

Report on the Explosion in

Frontier No. 1 Mine

Frontier, Wyoming

August 14, 1923

by

D. Harrington and H. E. Munn

Bureau of Mines

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R E P O R T

on

FRONTIER NO. 1 MINE EXPLOSION, FRONTIER, WYOMING.

August 14th, 1923.

by

D. Harrington, Supervising Mining Engineer,

and

H. E. Munn, Mining Engineer.

I N T R O D U C T I O N

On August 14th, 1923, about 8:20 A.M., an explosion occurred in the Frontier No. 1 Mine of the Kemmerer Coal Company at Frontier, Wyoming, resulting in the death of 99 men out of the total of 135 in the mine at that time. The only manifestation of the explosion at the surface consisted of a cloud of coal dust which issued from the fan discharge, and the blowing of some dust and papers from the manway. The fan was not stopped or damaged from the force of the explosion, but continued in operation, a fact which greatly hastened the work of rescue and recovery.

Observations made immediately following the explosion, and borne out by subsequent investigations, indicated that this explosion was accompanied by comparatively little violence, all the victims, with the possible exception of five men, meeting their death through inhaling the noxious gases present after the explosion, in an attempt to reach the surface immediately after the explosion. The other five met their death due to burns, or possibly a combination of burns and the inhalation of after-damp. The 36 men who survived were saved

by barricading themselves in the fresh air remaining on the inner portions of the entries, and by remaining in their working places until restoration of ventilation or the arrival of the rescue crews.

Car No. 2 of the U. S. Bureau of Mines, at Rock Springs, Wyoming, was advised of the disaster at 11:15 A.M. by Mr. E. S. Brooks, General Manager of the Union Pacific Coal Company, the information and call for the services of the Bureau men having been transmitted over the Union Pacific wires. A special engine was detailed by the Union Pacific Railroad Company for the run to Green River, Wyoming, within a very few minutes, Car 2 leaving Rock Springs at 11:30 A.M. with the right of way to Kemmerer. At Green River at noon, another engine of greater speed was coupled to Car 2 and proceeded immediately, arriving at Frontier about 1:20 P. M. Mr. Mum, Mining Engineer in charge of Car 2, conferred with Mr. P. J. Quealey, General Manager of the company, offering the services of the car's crew and equipment, this offer being accepted. Two apparatus crews composed of the personnel of Car 2, and apparatus men from the Cumberland Mine of the Union Pacific Coal Company were immediately organized. These crews participated actively in the work of recovery, several bodies being recovered with the apparatus.

GENERAL INFORMATION

Location, Ownership, etc.

The Frontier No. 1 Mine is one of a group of mines being operated by the Kemmerer Coal Company in this district. It is located about one mile north of the town of Kemmerer, Lincoln County, Wyoming, and is served by a branch line of the Oregon Short Line Railroad, Union Pacific System.

Mr. M. S. Kemmerer, 143 Liberty Street, New York City, is President.

Mr. P. J. Quealey is Vice President and General Manager of the company with headquarters at Kemmerer, Wyoming. Mr. Gomer Reese is General Superintendent of the company's mines in this group, and John Oakley is mine foreman at Frontier No. 1.

The Kemmerer Coal Company operates, in addition to the Frontier No. 1 Mine, what are known as the No. 4 Mine at Susie, the Nos. 5 and 6 Mines at Sublet, and the Elkol No. 1 Mine at Elkol, Wyoming. The remaining Mine, No. 3, adjoining No. 1, has been idle for some time.

The Frontier No. 1 Mine was opened in 1887 by P. J. Quealey and has operated nearly continuously ever since. The management has experienced several fires of more or less importance, but no serious disasters occurred until the explosion on August 14th, of this year.

The production of Frontier No. 1 at the time of the explosion was between 600 and 700 tons per day, the greater part of the production being taken by the Oregon Short Line Railroad.

Coal Occurrence.

The coal at Frontier No. 1 is Cretaceous, Frontier Formation, the measure worked being known as the Kemmerer vein. The coal is bright and fairly clean with a relatively high heating value, with a slight tendency toward coking. It will average between seven and eight feet in height, but thins out in places. The roof is shaly slate, having a tendency to come down in rather thin layers. The floor is slaty in character and has a tendency to heave, especially in the presence of considerable moisture. The dip varies, but will average somewhat less than 20 degrees. Although the mine produces considerable amounts of water, the coal itself is dry, especial-

ly in the rooms.

The coal analysis of a fresh face sample is as follows:

Moisture.....	5.90
Volatile Matter.....	38.10
Fixed Carbon.....	52.00
Ash.....	4.00
Heating Value.....	12850 B.T.U.

The sulphur content will average slightly over 1.00% and the ratio of volatile matter to volatile matter plus fixed carbon is about 0.42.

MINING METHODS AND CONDITIONS

Method of opening.

The Frontier No. 1 Mine is opened by means of a slope approximately 6000 feet long, having a pitch of 20 degrees or a little less. The general system of development is that commonly known as the "Double-entry room and pillar system", consisting of the main and back slope openings driven on the dip, with cross entries driven on the strike at intervals of about 400 feet. The entries on the right side are driven a short distance below the left side entries. Right side entries are designated by even numbers and those on the left by odd numbers. Entries are driven about 12 feet wide with a 40-foot pillar between; and are carried to the economical haulage limit or to destination. Rooms are driven from the entries up the pitch parallel to the main slope, a barrier pillar being left between the end of rooms and the back entry of the next level above. In general rooms are not driven through to the entries above except that the first room or few rooms near the slope may be driven through.

Blasting.

The coal is shot "off the solid" by means of FFF black powder, fuse and squibs being used as the igniting medium; no undercutting, overcutting or shearing is done. It is said that the coal shoots easily, in some cases two rib shots being sufficient to bring down a 20-foot room face. Holes are drilled as deep as 8 feet and stemming, derived from the fire clay seam underlying the coal more or less mixed with coal dust, is used. Shooting in rooms is done at noon and at the end of the shift, while entrymen are allowed to fire shots at any time. A Shotfirer is supplied for every producing entry and is supposed to inspect all shots and to know that surrounding conditions as to explosive gas are safe for blasting.

Haulage.

The coal is loaded at the face into wooden cars of the loose end gate type. The loaded cars are then lowered from the room face to the entry by means of a "McGinty" mechanism.

In the operation of the "McGinty" at this property, a single track is laid in the center of each room. Taking two adjacent rooms as an example, the loaded car is attached to one end of the steel "McGinty" cable, the cable passing around a sheave to the "McGinty" friction drum located in the crosscut between the two rooms. From the friction drum, the rope passed over another sheave in the second room, and down the room to the empty car at the room neck. In operation the loaded car is released and lowered to the room neck by means of the friction drum, the loaded car pulling up the empty car in the next room. Cars are gathered and distributed on the entries by horses. After a trip is gathered on the outside entry parting, it is

hauled up the main slope to the surface by the main outside steam hoist. The regular loaded trip consists of twelve cars. At the surface, the slope hoist places the trip on an outside parting, from which it is lowered to the tibble by a separate hoist.

The slope hoist is of the duplex steam driven type, rated at 1200 HP, and operating at an average rope speed of 1000 feet per minute while hoisting.

Timbering.

The roof conditions in general are excellent, very little timbering being required outside of the usual system of props in rooms and an occasional use of cross bar sets on entries, partings and room necks. The slate which lies immediately over the coal is rather tender and is disposed of by gobbing in rooms on either side of the track, props being set to catch the sandstone above.

Ventilation.

The mine is equipped with a Guibal fan installed in a wooden housing, and operated by a 100 HP electric motor, power being transmitted to the fan shaft through a silent chain drive. The fan operates exhausting and delivers to the surface approximately 70,000 cubic feet per minute at $2\frac{1}{2}$ inch water gage; however somewhat less than 50,000 cubic feet per minute goes below the 14th level to the active workings. Connection between the return air course (back slope) and the fan intake is through a rock shaft about thirty feet deep, thereby giving a certain amount of offset in the return near the fan. The mine has four main splits and one small split at the stable. Stoppings between the main and back slope are of masonry and were probably fairly tight

TABLE NO. 1

ANALYSES OF MINE AIR SAMPLES TAKEN IN FRONTIER NO. 1 MINE,

AFTER VENTILATION HAD BEEN RESTORED.

September 21, 1923.

By H. E. MUNN.

Bottle No.	Lab. No.	Quantity Cu. Ft. Per Minute	PERCENTAGES						LOCATION
			CO ₂	O ₂	CO	CH ₄	H ₂	N ₂	
330	18897	8500	0.17	20.42	0.00	0.18	0.00	79.23	Return from 30 Back Entry, 20 ft. below 29 Back on Backslope.
337	18898	72000	0.40	19.92	0.00	0.10	0.00	79.58	At Bottom of Main Air Shaft. Total Return from mine.
334	18899	4768	0.23	20.03	0.00	0.26	0.00	79.48	At foot of 1st slant. 28 Back Entry. Return from 28 Entry.
341	18900	4250	0.26	19.80	0.00	0.22	0.00	79.72	50 feet inside 1st slant 27 Back Entry. Return from 27 Entry.
333	18901	5500	0.20	20.16	0.00	0.30	0.00	79.34	40 ft. inside of back slope on 29 Back Entry. Return from 29 Entry.

previous to the explosion. Stoppings on entries are of the double dry wall with fine core type and show considerable leakage. Much brattice cloth is used in the construction of temporary entry stoppings, entry curtains and line brattices at room faces. Overcasts and undercasts are of permanent concrete construction.

In general the ventilating system consists of the main slope haulage way as the main intake and the back slope as the return. The intake air is taken into the workings through the haulage roads and diverted up the rooms by entry curtains. In general the return is through the back entry. Line brattices are maintained from last crosscuts on intake side of rooms to faces, in order to prevent methane accumulations.

Table No. 1, showing analyses of air samples taken several weeks after the explosion, after ventilation had been completely restored, will serve to show the condition of the mine atmosphere under ordinary operating conditions. These analyses, together with data in Table No. 2 covering the analyses of certain air samples taken after the explosion, will indicate that this mine generates sufficient methane to constitute a serious hazard in case of interrupted or insufficient ventilation.

Lighting.

No open lights are allowed in the mine, miners being furnished with electric cap lamps of the Wico type. The lamps furnished to miners are securely locked, whereas those furnished to company men are held closed by a nail or cotter key and can be opened with ease. The latter condition violates the schedule of permissibility for this lamp, and also introduces a hazard which should be eliminated. It is common practice for fire bosses to carry

an extra battery underground with them. Flame safety lamps for the use of fire bosses, and other officials, are mostly of the round wick Wolf keylock type. Some Wolf magnetic lock lamps are furnished but the dogs have been removed thereby rendering the locks ineffective. From information gathered at the time of the explosion, especially at the time of the coroners inquest, it appears that very little attention has been given in the past to the question of correct handling and maintenance of the flame safety lamps. It is understood that it is a common practice not to use the igniters, or to leave them out entirely, soldering up the recess, which has made it necessary to light the lamps underground by means of matches, in case the light became extinguished. No precautions are taken to prevent miners from taking matches or smoking or other inflammable materials into the mine, and smoking underground is a common practice.

Dust.

The coal is brittle and has a tendency to make a considerable amount of fines. The system of shooting "off the solid" with comparatively heavy charges of powder, further induces the production of dust, which settles on the room gobs and is carried to the entries, being deposited on timbers and rib ledges. Considerable accumulations of fine dry road dust are present in rooms, due in great measure to the type of cars used as well as to the use of the McGinty system with which wrecks of cars in rooms are common, causing additional accumulations of coal dust on roads, and also throwing the fine dust into suspension to be later deposited on gobs and timbers, ribs and roof.

Similar conditions exist on portions of the main entries and the slope haulage way where accumulations of road dust were noted; most of these

places there are wet zones with water drippers and these had a vital effect
 entries, no other means of artificial humidification is employed. In a few
 provision made to reduce dustiness of rooms. Outside of the pipe lines on
 and dustiest parts of the mine, no pipe lines are extended into them and no
 not been affected by the explosion. Although rooms are in general the driest
 accumulations of dry fine dust that were noted at several points which had
 beared necessary to those in charge of this work. This is borne out by the
 sprinkling was not systematically or regularly done, but rather when it ap-
 red from the pump columns. Mine conditions would seem to indicate that
 Provision is made for the sprinkling of entries from pipe lines
 equipment to remove water from the mine.
 for several years, the management spending large sums on power and pumping
 spring to fall season. The handling of this water has been a serious problem
 during the winter months, and as high as 900 gallons per minute during the
 pedally the rooms, the mine makes about 700 gallons of water per minute
 Notwithstanding the general dryness of the advancing workings, es-
 dust.
 dry though there are not many rib ledges to catch and hold dry fine dangerous
 dry sections or spots; ribs and roof of entries as well as rooms are generally
 sectional area. In general the floor of entries is damp to wet with occasional
 in those portions where the air velocity decreases due to increased cross-
 cars, which later is deposited on cross bars, ribs and the floor, especially
 300 feet per minute, sweeps large quantities of dry coal dust from loaded
 per minute on the main haulage against a ventilating current velocity of about
 eral floor of roadways cannot be called dry. The trip speed of 1000 feet
 accumulations contain large percentages of fine dry coal dust, though in gen-

in preventing spread of the explosion, this being true especially near the mouth of the 29th Entry and in the 28th near Room 21.

Fires and Fire Prevention.

The mine has a sealed fire zone on the left side of the main slope, between No. 1 Entry and the outcrop. This area has given no trouble for some time according to the information available. Mine fires at this property are, however, frequent, but fortunately it has been possible to extinguish them before any serious damage has been done. These fires are not the result of spontaneous combustion but occur following blasting, and are caused by the flame from black powder igniting the methane feeders, which in turn ignite the newly shot coal. From the information available it appears that these feeders are located principally in the fire clay which directly underlies the coal. This condition has become so troublesome that it has been necessary to employ what are known as "fire runners", whose duty is to follow up all shots and extinguish fires resulting from such shooting. A few days before the explosion, a fire of this character occurred in No. 12 room on No. 30 entry, getting considerable headway before it was finally extinguished.

Safety Measures and Equipment.

Five sets of Paul apparatus are maintained at this mine, the equipment being in the charge of Mr. Rex Coates, Engineer, and a crew of five men is trained in the wearing of the apparatus. Universal gas masks are used for fighting fires, the oxygen breathing apparatus being sent for only in cases where the fire has gotten considerable headway.

A first-aid station is maintained at a point on the main slope, and is equipped with necessary first-aid materials and stretchers.

A rigid system of checking men in and out of the mine is efficiently maintained, a measure which proved very valuable in checking and identifying the 99 men killed in this disaster.

Sprinkling and fire lines, of one inch diameter, are maintained on all entries, but as before stated, are not extended into rooms.

STORY OF THE EXPLOSION

The explosion occurred about 8:20 A.M. August 14, 1923, there being 135 men in the mine at the time. Mine Foreman Oakley was still on the surface, and he and some of the surface crew noted the cloud of dust which issued from the fan discharge, also that papers and other rubbish were blown out of the manway. The fan did not stop, nor was it visibly damaged by the force of the explosion.

Mr. Gomer Reese, General Superintendent, was away on his vacation, and Mr. P. J. Quealey, Vice President and General Manager, took active charge in his absence. Calls for assistance were sent to Cumberland and to Diamondville, Wyoming; the apparatus crew from Cumberland responded immediately, accompanied by Mr. George Brown, Superintendent, likewise Mr. Russell of Diamondville responded with some of his men and five sets of apparatus. The apparatus belonging to the company was also made available, although three of the rescue team had been killed by the explosion. Three men wearing apparatus went underground as far as 20 entry, returning to No. 17 entry, where the apparatus was abandoned. This was the only attempt made to use apparatus

prior to the arrival of Car 2 of the U. S. Bureau of Mines at 1:20 P.M.

Immediately following the explosion, three men were sent down the slope to examine the entry stoppings. Mine Foreman Oakley and several helpers proceeded down the slope and found the pumper's body between 14 and 15 entry. The trip was at 17 entry wrecked and three men were sent to pull the pin so that the rope could be hoisted to the surface, and a short trip of empty cars from the surface be used for transportation of materials as well as for rescue and recovery operations. Work was started immediately on the construction of brattice stoppings to replace those permanent stoppings between the slope and return airway which had been damaged, ventilation on the main slope being restored as far as 29 entry at about 11:30 A.M. The work of cleaning the slope was comparatively easy due to the lack of violence, very few falls of rock being encountered and most of the stoppings being blown away from the slope. The first signs of violence were noted just below 15 entry, where several roof falls were found. The slope was completely cleared of all obstruction at about 2:00 P.M.

In the meanwhile, rescue crews, composed of mine officials and workers from various parts of the district, conducted explorations into the entries in which men were known to have been working. Entries 25, 27, 28 and 29 were explored in this manner without the use of apparatus, the parties advancing with flame safety lamps. This work resulted in the rescue of 33 of the 36 survivors, the remaining 3 men having found their way from 28 entry to the surface unaided. In all cases where men survived, it was entirely due to their own headwork, in either erecting barricades to keep out the afterdamp, or in remaining back in their working places until the arrival of rescue crews.

No. 30 entry, the lowest entry in the mine, was filled with afterdamp almost to the outside parting, and rescue parties were unable to explore it without apparatus. Immediately after the arrival of Car 2 of the Bureau of Mines, an apparatus crew composed of the personnel of the Car, with two additional men, made a preliminary examination of No. 30 entry, advancing far enough to convince themselves that no live men were in that section of the mine.

Due to the fact that most of the victims met their deaths by inhaling afterdamp, on or near the main slope, the recovery work was comparatively easy, and especially so with ventilation practically restored to the bottom entry. By 1:30 A. M. August 15, 93 bodies had been recovered, with 6 still unaccounted for. Three of these were recovered in the forenoon of August 15th, by apparatus crews, two more at about 7:00 P.M. of the same day, and the last body, that of Fire Boss Tom Roberts, at 1:30 A.M. August 16th, completing the check, with all bodies identified.

While there were 135 men in the mine at the time of the explosion the death list was but 99; hence there were 36 survivors and some of the stories related at the coroner's inquest by survivors were decidedly interesting even though somewhat conflicting. In one instance two Japs were working in a room off the 28th level inside of Room 21 and at the time of the explosion heard little or no noise and felt only a comparatively slight concussion, manifested chiefly on the ear drums. The men felt that something was wrong and went down the room to the entry but on encountering smoke and heated air returned to the room face. In about an hour they again went down with the same result; and again at about 11:00 A.M. they went down, this time going out almost to the main slope through the air was bad (giving headache)

and they stepped over several bodies. Near the slope they again encountered dense smoke and retreated to their room where they remained until nearly 5:00 P.M. when they walked out to the surface unharmed and unaided.

In another case either 21 or 22 men barricaded themselves on the 29th Entry and came out alive about 3:00 P.M. The explosion scarcely entered the 29th entry and while flame traversed the 27th entry to Room 47, it did not go into rooms off the 27th entry nor did the gases appear to go very far either into the 29th Entry, or into the 27th beyond Room 49. Men working at or near the face of the 29th entry felt the concussion on the ear drums and stated that there were two or more waves. Several men started out and reached Room 1 off 29th Entry when stopped by smoke; meanwhile a shot firer named Pavlisin tried to get out by going through Room 4 to the 27th where he found several live men but also was confronted by smoke and heated air when approaching the slope. Feeling that immediate escape was cut off and that the best opportunity for prolonging or saving life would be by going back into the 29th Entry where he had been working, it appears that Pavlisin retreated to the 29th with some of the survivors from the 27th level. They, with such of the survivors from the 29th as hadn't tried to force their way out (in which case they met death), retreated towards face of the 29th Entries. In about an hour they again tried to go out and this time found that the smoke was gradually coming into the 29th as they were unable to go beyond Room 5. It was then determined to barricade themselves in the interior of the 29th Entry and three canvas brattices and one rock wall were constructed largely under the leadership of Pavlisin, though the matter of leadership is in dispute.

A brattice of canvas was thrown across the 29th Entry just outside of Room 13, another in the 29th Level just inside of the location of Room 21 and a third is said to have been built presumably closing a cross cut between Rooms 12 and 13. Pavlisin opened the door in the slant cross cut just outside Room 13 with intent to short circuit the smoke and fumes, a very good idea though it seems to have been violently opposed by some of the imprisoned men and in order to satisfy them, a rock barricade was constructed in the 29th Back Entry about 100 feet inside of the lower end of the slant in which the door had been opened. This barricade was built of two loose rock walls with faces about 18 inches apart and the space between walls filled with loose dirt (coal dust and slack coal); there was an abundance of materials at hand from scaling of roof. It required some hours to build this barricade but when constructed it was both tight and substantial. When the barricading work started it is said there were over 30 men in the crowd but several insisted on going out and these were later on found dead on the 29th parting near the slope; on the other hand the 21 or 22 who remained were able to leave the barricaded region about 2:00 P.M. and reached the surface safely about 3:00 P.M., ventilation having been partly reestablished. These men were in the mine at least 6 hours after the explosion.

There were 21 men in the 30th level and rooms above it and it is probable that they had practically no chance of escape; except for these and a few who were on the main slope and on the main 27th and 28th Levels at the time of the explosion, there is every reason to believe that had the men remained in their working places, they would have come out alive, particularly if they took measures to short circuit the circulating air away from their working places or built canvas or other brattices closing off their working

places. This would probably have reduced the death list to fewer than 30.

Bureau of Mines Activities.

Word of the disaster and the call for assistance was received by Car 2 of the Bureau of Mines at Rock Springs, Wyoming at 11:15 A.M. on August 14th. Within 15 minutes the Car left Rock Springs with a special engine, arriving at Green River at 12 o'clock noon. The disaster report was confirmed at this point. At Granger, Wyoming, the following message was received from Frontier "Come as quickly as you possibly can with safety. We are waiting for you." A record run was made from this point, arriving at Frontier at about 1:20 P.M. Practically immediately after arrival of Car 2, two rescue crews were organized and held in readiness to enter the mine when called.

A preliminary examination of No. 30 entry was made by an apparatus crew consisting of Messrs. Munn, Sullivan and Birchard, with two additional men, and three bodies were recovered in 30 entry; explorations of all rooms were made by apparatus wearers under the leadership of Foreman Miner W. F. Sullivan; and the body of a Jap was found in Room 7. During the subsequent investigative work, the open safety lamp of Fire Boss Tom Roberts was recovered in an apparatus exploration of about 50 feet by Foreman Miner Sullivan, First-Aid Miner Birchard and Pete Bohm from the Cumberland mine of the Union Pacific Coal Company.

MINE INVESTIGATIONS

Source of the Explosion

On the surface, during the first day, the usual rumors as to the

cause of the disaster, were prevalent. Theories ranging from "blown-out" shots, runaway trip and smoking, to the intentional crime of a man who afterward had committed suicide underground, were freely discussed.

In the course of the rescue and recovery work, it was noted that conditions in and about the 30 entry indicated that it was probably the source of the explosion. The fact that no men were found living in this entry, together with evidences of heat and violence in excess of that found in other portions of the mine, tended to strengthen this theory.

D. Harrington, Supervising Mining Engineer of the Bureau, arrived at Frontier on August 15th, and conferred with H. E. Munn in regard to underground conditions and the proposed investigative work. On the morning of August 16th an inspection of the property was made by the following:

Representing the Company, John Oakley, Mine Foreman.

Rex Coates, Engineer.

Representing the State, Pete Patterson, State Coal Mine Inspector.

Representing the Bureau of Mines, D. Harrington, Supervising Mining Engineer.

H. E. Munn, Mining Engineer, Car 2.

W. F. Sullivan, Foreman Miner, Car 2.

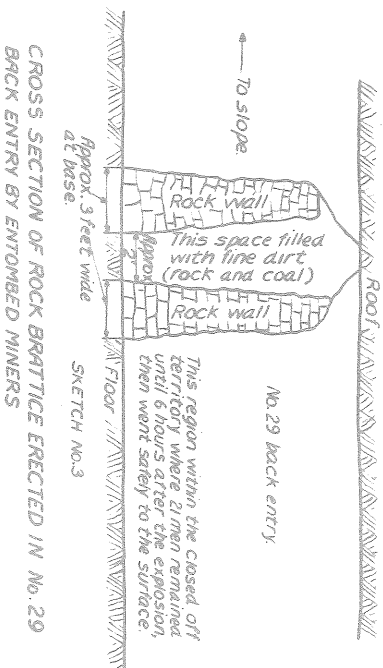
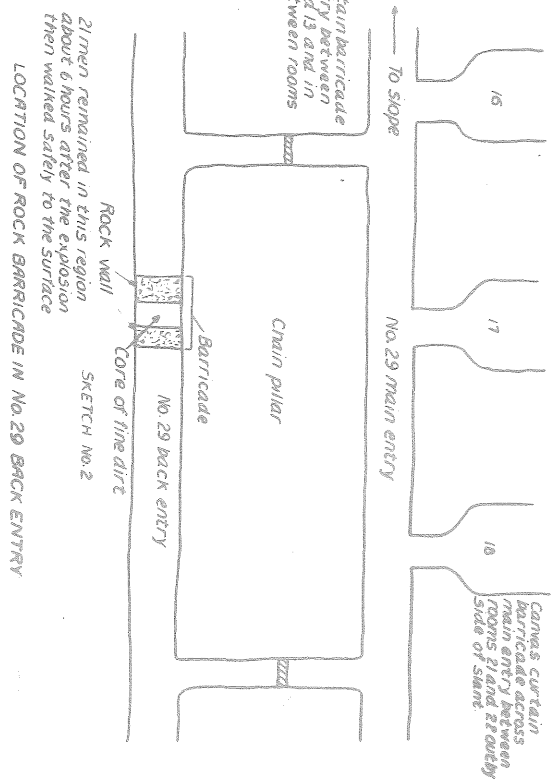
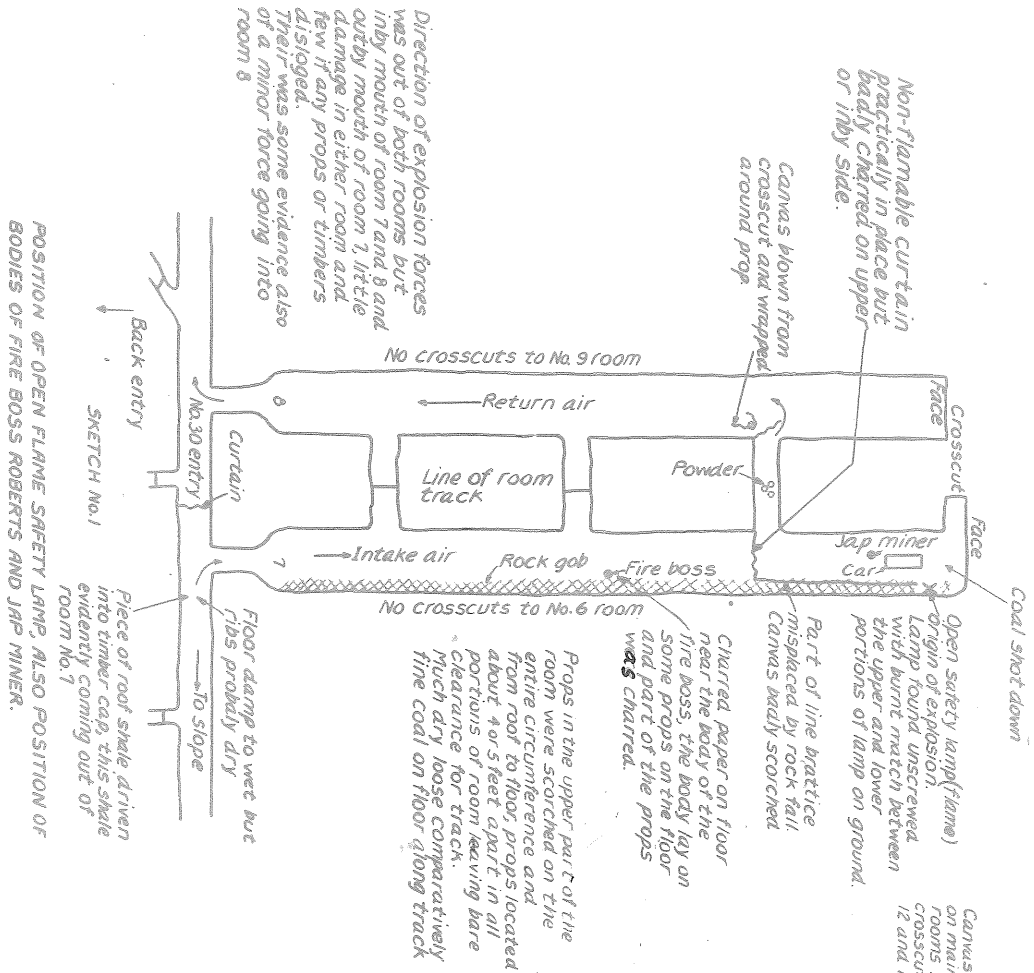
R. E. Birchard, First-Aid Miner,
Car 2.

The investigative work started in 30 Entry. Proceeding in from the slope parting, over the main entry, the timber was not disturbed, only showing deposits of coal dust on the inby faces of props and cross bars. Comparatively little evidence of intense flame was noted, although some splinters on posts were scorched and bodies previously found on this entry were badly burned. At No. 5 Room the box and bucket of Shot-Firer Tom Roberts were found, it being noted that he had not touched the food in the bucket though it was his custom to eat his breakfast immediately upon reaching underground for the day shift. At No. 7 Room, a car standing close to the room neck was thrown outby

a distance of about two feet. Room 7 was up about 200 feet and was connected to Room 8 by three crosscuts, with an additional crosscut near the face not completed. These two rooms were isolated from the adjoining rooms, there being no crosscuts from Room 7 to Room 6 nor from Room 8 to Room 9. (See sketch). Examination of the props in Room 7 showed the effects of intense heat from floor to roof especially on the right side of the room. There was a considerable amount of dry road dust in Room 7, also the rock gob on either side of the track was well covered with fine dry dust. Shot-Firer Robert's body, when found, was to the right of the track, about 60 feet from the face and about 15 feet above the second crosscut to Room 8. Robert's body was badly burned, especially about the upper part. The badly burned body of a Jap miner in No. 7 Room had been recovered about 7 feet from the face of his room, by an apparatus crew. The investigating party was unable to get to the face, due to the presence of gas which was sampled and when analyzed at Pittsburgh, Pennsylvania, was found to contain 1.4 CO₂, 10.2% oxygen, 0.7 CO, 10.6% methane, 0.7% hydrogen and 76.4% nitrogen. Near the face, on the gob at the right side of the room, where a line brattice had fallen, the open safety lamp belonging to Shot-Firer Tom Roberts, was found, the relative position of the parts being as shown in the attached sketch. From the evidence at hand, Roberts lost light of his flame safety lamp, possibly by having jerked it out, or more probably the light was extinguished by methane explosion within the lamp. Thinking he was safe on the intake air side of the line brattice, he opened the flame safety lamp and attempted to relight it with an ordinary match, of which the wooden part with tip charred was found lying beside the fuel container on the floor, the upper part of the safety lamp being found a few feet from the fuel container or lower part. Apparently a body of gas had

accumulated at the face through the fact that the line brattice was partly thrown down by a rock fall. With the ignition of the gas, Roberts apparently ran down the room to the point about 50 or 60 feet distant where his body was later found. The flame undoubtedly caught the Jap miner near the room face and in standing position, hence the heat was concentrated and his death caused by burns was nearly instantaneous. Roberts, probably kneeling or sitting on the floor relighting his lamp encountered less flame immediately than did the Jap hence was able to go about 60 feet before dying. Roberts had evidently been called by the Jap digger into No. 7 to repair the line brattice which had apparently been knocked down by a fall of roof sometime between the hour of the Fire Boss' examination and the time the Jap entered his place.

A brattice curtain which had been strung across the room to within four feet of the right rib from a point below the last crosscut to No. 8, and through which mules, cars and men could travel, was badly burned on the upper side, and not so much on the lower side. There was very little violence in the upper part of Room 7, only a part of the brattice being dislodged. Retreating to the 3rd cross cut, and through same to No. 8 Room, evidences of considerable heat coming from 7 Room and proceeding down No. 8 were noted. In addition, evidences of force coming up No. 8 room from the entry were noted. Room 8 was very little disturbed. Opposite the last cross cut from Room 7, a piece of brattice was found wrapped around a prop in such a way as to indicate that it came from Room 7. Further investigation on the 30 main entry showed that pit cars at necks of rooms 11 and 13 were forced in by toward the face of the entry. This was true also of entry curtains, which in all cases on the inside of No. 7 Room were blown toward the entry face. These observations indicated strongly that the origin of the explosion must have been in or near No. 7 Room.



John Sager, Jr. Fire Boss, was regularly employed to examine working places in No. 29 and 30 entries before the shift went to work. On the morning of August 14th, he made the following report in the book of "Fire Boss Daily Reports.":

8-14-25.

"Tuesday, between 5 and 7 A.M. I examined all of the working places on 29 and 30 entries and I find them all clear of gas."

(Signed) John Sager, Jr."

Tom Roberts, shot-firer, but also certified as fire boss, was taking his brother's place as Fire Boss on 27 and 28 entries, and on the morning of August 14th, Roberts, acting as fire boss, reported 50 feet of gas at face of 45 room on 27 entry. Mine Foreman Oakley ordered Roberts to fire shots in 30 entry on the day shift, Sager to shoot in 28 entry, and Joe Wainwright, Safety Inspector, to remove the gas in 45 room on 27 entry.

Under ordinary circumstances, Roberts would have eaten his breakfast as soon as he arrived on 30 entry, before starting on his work as shot firer. The fact that he did not touch his breakfast would seem to indicate that he was called to take care of some condition demanding his immediate attention. As heretofore stated, the Jap in Room 7, upon reaching his working place, probably noted that the face brattice had been disarranged by a rock fall, returned at once to the entry and meeting Roberts coming in, asked him to repair the brattice. Roberts was engaged in this work when his safety lamp became extinguished. His action in attempting to relight it with a match, in the presence of a methane accumulation, resulted in his own death, and the death of 98 of his fellow workmen.

After having thoroughly examined Rooms 7 and 8 off 30 entry, the investigation was continued to determine the path of the flame and the length

of travel, as well as to note other conditions having a bearing on the extension of the flame and gases into other parts of the mine. Further examination of 30 entry indicated that the explosion coming out of 7 room, split at the room neck at the entry, part of the force traveling towards the face, blowing the doors in slants and some of the gob stoppings, and returning through the back entry to the slope. A piece of brattice cloth from the door in the second slant was caught on a projecting rock in such a way as to indicate force coming from the back entry through the slant. About 20 feet outby No. 7 room neck, a piece of slate was forced into a cap piece near the low rib of the entry and on line with room 7, showing a force coming out of room 7 and in a direction toward the main slope. The slope pump station, situated about 40 feet below the entrance to 30 entry, was not damaged, and there was very little damage to the 30th Main and Back Entries other than the forcing of a few stoppings and doors but occasionally scorching splinters on timber caps or legs.

The course of the explosion was up the slope, indications of flame being evident, but with comparatively little violence. The parting at 29 entry was damp, but the flame entered and extended as far as Room 6. There was a wet zone with occasional drippers, extending from a point about 100 feet from the slope to about 350 feet from the slope. The drippers, and damp zone of about 200 to 250 feet near the mouth of 29 entry, absolutely stopped the explosion outside of No. 6 room. No indications of flame or violence were found inby the inside boundary of this wet zone, even though there was much dry dust immediately inbye. Rooms of 29 entry were not damaged either by flame or violence, nor did the after-damp (explosion gases) proceed very far or very quickly into the 29th entries or rooms above them.

Continuing up the slope, the explosion entered 27 entry and extended to No. 47 room, as evidenced by flame indications, but practically no signs of violence were present, with the exception of the blowing out of entry brattice curtains. On the average these entry curtains were blown to a distance of 25 to 30 feet inbye their original positions. Flame indications were well defined on many timbers, as well as on numerous pieces of entry curtains left in place and partly burned. The curtain just inbye room 47 had several holes burned in it but no signs of flame were noted at the curtain at 49 room, not even dry lint and fringes showing any sign of flame and the curtain had not been torn or otherwise disturbed. No flame entered rooms 45 or 46, although fire boss had reported gas in 45 room that morning, and there was no evidence of flame or violence inbye 49 room. Three horses were killed on this entry, all being badly burned. One horse was brought out alive after the explosion, from a point inbye No. 49 room, showing conclusively that neither flame nor gases extended much if any inbye Room 49. Men working in the rooms off 27 entry were not mangled or burned, but many of them were subsequently killed by gas in attempt to escape up the slope, and most of the bodies were found on the outside parting at the slope. Safety Inspector Wainwright and the shot firer who moved the gas from No. 45 room, were both badly burned; Wainwright's body was found on the parting near the slope, and the shotfirer's just inside of No. 45 room. Wainwright's coat, hanging on a nail driven into a prop inbye the outside parting, was completely burned and set fire to the prop. This burning prop was close to a crushed entry pillar with considerable fine coal present, and no doubt would have been the starting point of a serious fire had the oxygen content in the afterdamp been sufficient to support combustion. There was ample evidence of numerous

fires started on the 27th Entry and apparently all were extinguished by oxygen deficiency as there was an abundance of dry combustible matter available, but there were no live fires found when the rescuers entered these places.

Inspection of 28 entry, which leaves the slope a short distance below 27 entry, showed that the flame entered this district but there was little or no violence. Evidences of flame on splinters on props and on brattice fringes were quite marked as far as Room 11, where the exploration was discontinued due to the fact that the entry inbye was completely filled with methane from this point to the face. Later it was found that flame extended as far as Room 21 where it was stopped apparently by a damp to wet zone in the entry outbye Room 21. A lunch bucket, located at the first slant, showed the contents completely charred, indicating the intensity of the flame at that point.

At the underground stable located just off the main slope below the 28th Back Entry there was no violence and practically no evidence of heat though there was an abundance of flammable material present. Above the 27th Levels on the slope there was comparatively little evidence of violence and only occasionally any evidence of flame. The slope floor was damp to wet along ribs but in places dry along track and the ribs and roof were almost uniformly dry, though in a few places there was some dampness evident on caps or on roof material. The pumpman going up the slope from lower pumps was found dead on the slope near the 25th Level. Between the 26th and 20th levels at the slope there was not very much evidence of flame and only a limited amount of violence, though the overcasts at the 20th and 22nd levels were blown outbye and the one at the 24th damaged while stoppings between the main intake slope and the return slope were either forced towards return or more or less damaged.

There is a "bottle neck" in the slope region between the 16th and 20th levels as there were practically no workings either to the right or left of the slopes in this region and here there was a concentration of forces and some added violence. The trip was wrecked on the slope about the region of the 17th Entry, some timbers were blown out and the undercast at the 17th and return air course was forced. Flame was traced up the slope about as far as the 15th Entries but it apparently died when it encountered the wet place in the slope just below the 13th. Above the 15th there was little evidence of violence except that a few of the stoppings were slightly broken and at the 10th Back Entry an abandoned overcast wall was forced into the slope. There was no evidence of an explosion at the surface except the smoke from the return air escaping from the fan.

In proceeding down the main slope from the pit mouth after the explosion, about 250 feet of very fine dry dust was found, followed by a damp zone. About the 7th entry, several hundred feet of slope floor was covered with very fine, dry coal dust. From this point on to the bottom entry, the slope was found to be damp to wet formost of the distance, with occasional dry spots of 50 feet or more intervening. In all cases where dry dust was found, a considerable percentage of fines was noted.

Careful examination of all the workings affected show the presence of coke, only in a few instances, indications of heat being confined to the baking and charring of timbers, paper, etc., and the burning of brattice cloth and of miners.

Distribution of Forces.

The map of the Frontier Mine, included in the appendix to this report, shows the direction and distribution of the forces resulting from the explosion.

The explosion unquestionably had its origin at the face of No. 7 room of 30 entry, due to the ignition of a body of gas by relighting of a flame safety lamp by an ordinary match in the hands of Shot firer Roberts. The force of this local gas explosion was sufficient to throw into suspension the fine dry coal dust from floor, ribs and timbers, thereby propagating the flame to the points heretofore mentioned, and indicated on the mine map.

30 Entry:

The flame and comparatively light force split near the face of No. 7 room, the major part going directly down No. 7 to the entry, a smaller portion going into No. 8 room through the top crosscut. At the entry, the force from No. 7, split two ways, part going towards the slope, part towards the face of the entry. That part going inbye over the main entry was of sufficient force to blow two stoppings and the doors in the 2nd and 3rd slants, the direction being from main to back entry. Some of the flame and force also went into the rooms inbye No. 7 Room.

29 Entry:

The flame entered the main entry from the slope, reaching a point between Rooms 4 and 5, but not as far as Room 6. The wet zone of 200 to 250

feet in length, and at a distance of about 100 feet from the slope, absolutely stopped the explosion at this point. No stoppings were blown in this entry although the undercast was slightly damaged. The flame penetrated the wet zone at least 150 feet as shown by charred splinters on timbers which evidently were damp when the flame encountered them.

28 Entry.

The flame entered the main entry from the slope. No evidences of violence were present, but the heat was intense. There was some sloughing of loose material from upper rib along the 28th Entry between room necks, also a few slight roof falls but there was practically no blowing down of timbers. Flame evidence was found to about Room 21, the flame being "killed" apparently by the damp to wet zone just outbye Room 21. The floor of the 28th Entry could be rated damp to wet, with ribs and roof at least fairly dry. Inbye Room 21 five men were working and all came out alive as they waited until ventilation was at least partly restored.

27 Entry.

Flame entered the 27th main entry, reaching as far as No. 47 room. No rooms were damaged, and there was little or no violence on the entry. Stoppings remained intact, although slant doors were blown towards the back entry. The undercast on this entry was slightly damaged. There were numerous evidences of flame along the 27th Entry and some evidences of coking on timbers. The entry was dry especially as to the ribs and roof.

25 Entry:

Flame entered this entry a distance of about 150 feet. A door at the entrance to the main entry, just off the slope was blown inbye but not badly damaged. Evidences of considerable heat were noted on the parting, although the flame was not propagated inside the parting.

Main Slope:

Examination of the main slope showed that the flame extended to about the 2nd crosscut below 15 back entry, while the force of the explosion extended to the crosscut below 13 entry, at which point a hole was blown in a concrete stopping. It may well be said that the region of greatest violence occurred between 15 and 20 entries. This portion of the slope runs through a "want" and no entries were driven from the slope between the boundaries of this region, with the result that the force had no opportunity to expand until it reached 15 entry. Above 15 entry very little evidence of violence was present.

DISCUSSION AND CONCLUSIONS

General:

There is no doubt that the explosion in Frontier No. 1 Mine on August 14 was caused by the ignition of methane which had accumulated at the face of No. 7 room in 30 entry, by Shot Firer Roberts in attempting to re-light a flame safety lamp with a match. The ignition of this methane caused a local explosion of sufficient violence to stir up and throw into suspension the accumulations of fine coal dust which were found on the room gob and on

floors and timbers. This coal dust furnished fuel for the propagation of the explosion which proceeded out of 30 entry into the main slope and thence into four of the main working entries of the mine, with a maximum travel of approximately 4600 feet.

From the evidence at hand the accumulation of methane at the face of No. 7 room on 30 entry was possibly caused by the breaking of a line brattice through a fall of roof sometime between the hour when the Fire Boss had made his examination and the entrance of the miner into his working place. Fire Boss Sager, in making his report for the morning inspection, stated that all working faces off 30 Entry which included Room 7 were free of gas. Shot Firer Roberts, detailed on this entry on this day, was probably called to the face of room 7 by the Jap miners as soon as he reached the entry, and apparently he proceeded to repair the line brattice before eating his breakfast. The flame on his round wick Wolfe safety lamp became extinguished, either due to a sudden jar or possibly his lamp was not lit when he entered the mine, or the flame may have been extinguished upon being suddenly placed in an explosive mixture of methane. If his lamp had been extinguished by methane it seems improbable that he would have attempted to light it with a match, but would have retreated to the main slope before attempting such action; yet his lamp was found disassembled but each part in good condition and a burnt match near by and all on the intake side of the line brattice indicating that he might have encountered methane at the face and felt safe to light a match on the intake side of the line brattice.

There is another possibility and in some features it seems more probable than the foregoing. An inspection of Table No. 1 shows that the

the entire 30th Entry at an ordinary working period had but 0.18% methane in the total flow of 8500 cubic feet of air per minute or about 15 cubic feet of methane per minute for the entire 30th level split. There are at least 15 faces and this would give an average of approximately 1 cubic foot of methane per minute for each face. It should not have been over three hours from the time Fire Boss Sager left Room 7 on his morning inspection until the explosion occurred and if the brattice in Room 7 were disarranged immediately after the departure of Sager from Room 7, there shouldn't have been over 180 to 200 cubic feet of methane in the room and that amount would certainly not have filled the face practically down to the floor of a room 20 feet wide and over 7 feet high and on a pitch of about 15; and apparently there was methane almost to the floor at a point about 10 feet from the face as shot firer Roberts must have been sitting or kneeling down when he unscrewed his safety lamp and struck the match which ignited the gas.

From the foregoing it seems possible, even probable, that if Fire Boss Sager actually went to the face of Room 7 on the morning of August 14 (and it was not absolutely established that he had been there), he encountered a methane accumulation and instead of reporting it on the Fire Bosses' Book on the surface, "tipped off" Shot Firer Roberts and the latter immediately upon going underground proceeded to remove the methane with resultant explosion.

The one outstanding feature in this explosion is the fact that although the flame was propagated to a considerable distance into the entries and also up the main slope, there was comparatively little violence in any part of the mine. Numerous instances were noted where props could have been

dislodged by a man's weight being placed against them, still they were left standing in their original positions after the explosion. The path of the flame was indicated chiefly by scorching of props and timbers, the intensity of this condition decreasing as the stopping points were reached. The flame appeared to travel largely in the center of entries as frequently dry props with abundance of splinters showed no scorching yet farther on there would be ample evidence of flame which must have gone by the above mentioned unaffected timbers. Practically no violence to bodies was noted, although in several cases men died from the effects of burning or from the combination of burning and inhalation of the afterdamp, or of heated air, or of a combination of these.

There has been a strong impression that coal dust did not enter into this explosion. However, when it is considered that flame was transmitted at least 4500 feet in one direction, and over 3000 feet in each of two other directions and chiefly along intake air courses (haulage ways), the destructive forces generally going out of rather than into these intake air courses, it is simply inconceivable that methane could or did furnish all the fuel. Moreover, there was no evidence of any general interruption of ventilation before the explosion and according to Table No. 1 methane content of return air is not high. There appears to be absolutely no doubt that coal dust furnished most of, indeed practically all of, the fuel for the propagation of the explosion, yet fortunately the quantity of dust available at points readily reached by the flame was not sufficient to cause excessive violence. While the path of the explosion entered all of the operating entries, and attained a travel of some 4500 feet in one

instance, and attained sufficient force to blow out several concrete stoppings and overcasts, the explosion was not accompanied by any marked violence. Timbers were left standing that could be easily displaced by throwing a man's weight on them, pit cars in the direct path of the explosion were not damaged, and few if any of the bodies observed showed any signs of violence.

Ventilation:

A study of the tabulations of air analyses taken immediately following the explosion as well as those obtained after ventilation had been restored, will indicate that the mine generates sufficient amounts of methane that if ventilation should be interrupted, dangerous accumulations of explosive gas would undoubtedly be present at working faces. Although considerable attention has been given to the question of conducting the available air to all working places, these efforts have been largely nullified by the lack of sufficient volume.

Measurements taken in the main return near the fan give around 70,000 cubic feet per minute but measurements of the combined intake going down the main slope and right slope air course below the 14th levels, hence constituting maximum quantity for the working parts of the mine, was about 45,000 cubic feet per minute showing a leakage less of about 25,000 cubic feet per minute between the mouth of the mine and the 14th Levels. Table #1 shows that by measurements taken on September 21, 1923, by H. E. Munn, there was but about 23,000 cubic feet per minute actually in circulation in the working parts of the mine divided as follows: 27th Levels 4300, 28th Levels 4800, 29th Levels 5500, and 30th Levels 8500. This again indicates excessive leakage, this time between the region of the 14th Levels and the lower or

TABLE NO. 2

MINE AIR ANALYSES OF SAMPLES TAKEN IN FRONTIER NO. 1 MINE

AFTER THE EXPLOSION

By D. HARRINGTON and H. E. MUNE

August 16, 1923.

Bottle No.	Lab. No.	Quantity Cu.Ft. Per Minute	PERCENTAGES						LOCATION
			CO ₂	O ₂	CO	CH ₄	H ₂	N ₂	
329	18691	-----	0.80	13.50	0.50	7.00	0.30	78.10	:10 ft. from Face No. 7 Room : off 30 Entry.
331	18690	-----	1.40	10.30	0.70	10.60	0.70	76.40	:10 ft. from Face No. 7 Room : off 30 Entry.
332	18686	-----	1.40	13.70	0.40	13.30	0.40	70.80	:Inside last crosscut at face : No. 30 Entry.
342	18687	-----	1.40	13.70	0.50	13.30	0.40	70.70	:Inside last crosscut at face : No. 30 Entry.
547	18688	72,000	0.35	20.07	0.01	0.06	0.00	79.51	:In main return air course : near fan.
548	18689	-----	0.19	20.37	0.00	0.00	0.00	79.44	:Intake No. 3 Main Entry in- : side of overcast.

working parts of the mine. While the idea of keeping each level as a separate split would be a good one if there were available sufficient air to give each split about 15,000 cubic feet per minute, the present quantity circulating on each split (from 4300 to 8500 cubic feet per minute) is entirely too small.

The fan installation is decidedly inadequate, despite efforts which have been made to increase the amount delivered. As heretofore stated, the mine is ventilated by a single fan of the Gubal type, operating in a wooden housing. This fan is rated at 200,000 to 250,000 cubic feet per minute at 4 inches water gage and it is stated by the mine officials that a volume approaching these figures has been obtained in the past. However, for several years, it has not been possible to obtain in excess of 70,000 to 80,000 cubic feet per minute. An inspection of the fan shows that the wooden housing is leaking badly, and in addition considerable leakage is taking place in the masonry foundation walls. Also, the cut-off has been raised about 5 feet from the original position which probably has considerable ^{do} with the lowered efficiency of the equipment. Moreover there is excessive leakage underground through stoppings.

In the ordinary course of operation, the fan, must, at certain periods, be stopped for inspection, repairs, etc., and during this period dangerous accumulations of methane will undoubtedly be present in nearly all working places, but especially in the abandoned places. These accumulations would be decidedly dangerous under the present methods of shooting with black powder, with the use of fuse and squibbs as the igniting medium, to say nothing of the evident prevalence of smoking and other dangerous practices.

Shotfiring.

While this explosion was not connected with blasting, the blasting practices in this mine are certainly not good; the coal is "shot off the solid," FFF black powder is used with squibs or fuse, entry men blast whenever they please and room men are allowed to blast at noon when practically the entire shift is in the mine, and it is said that methane feeders from the floor are frequently ignited by shots with consequent fires. Each of the above practices and methods is dangerous in itself and when combined and added to the fact that the coal at least at room faces is dry and friable, it seems almost a miracle that explosions have not occurred from blasting. While it may appear to be impracticable at first thought, there is absolutely no reason why the coal even with present system, cannot be blasted by shot firers after the shift is off. Also electric blasting is much safer than fuses or squibs and wholly practicable. While permissible explosives are not at their best when shot on the solid, there is no good reason why a suitable permissible explosive may not be found to displace black powder and with permissible explosive there should be electric blasting.

This mine apparently has much available acreage for the future and in the interest of safety as well as of efficiency and coal conservation, consideration should be given the idea of conducting operations below the 30th Levels upon a panel system such as that used on a similar pitch at Gebo, Wyoming, and described in Technical Paper #154, U. S. Bureau of Mines, Pages 11 to 15, and in Volume 1 of the 1923 Proceedings of The Rocky Mountain Coal Mining Institute, pages 45 to 52. The above mentioned system will allow of undercutting of all coal with use of permissible explosives and electric blasting, will decrease percentage of fine coal produced, allow of doing all

blasting after the working shift has gone and in case of fire the panel in which the fire is located can be quickly sealed. Moreover with the panel system, pillars can be pulled and when a panel is worked out the placing of a few concrete stoppings, effectively seals the region and isolates abandoned territory from live workings.

With the adoption of permissible explosive, and some means of electric firing of shots there would be no necessity of carrying matches into the mine as smoking should be prohibited and a systematic and rigid examination of men for matches and smoking materials should be instituted, and every precaution taken to prevent lax and careless methods of searching. In addition to this, no flame safety lamps should be allowed in the mine, except those which are of an approved type and equipped with magnetic locks, and kept in working condition, and the men carrying these lamps should be required to demonstrate that they understand the dangers and limitations of the lamps and are competent to handle them; consideration should be given the use of Burrell Methane Indicator instead of flame safety lamps, at least when the working shift is in the mine. Great care should be exercised in the selection of underground officials, especially foremen, fire bosses and shot firers. Irrespective of capital and effort put into a property to provide the most safe and efficient devices and practices, these efforts on the part of the operator become ineffective if careless or inefficient men are in charge of actual operations.

Dust:

There has been a decided tendency towards belief that dust did not enter into this explosion and even that dust from Wyoming mines in general is non-explosive or at any rate can be ignited and exploded underground only with difficulty. There appears to be absolutely no question that dust entered into the Kemmerer explosion, otherwise it would be impossible to account for transmittal of flame, chiefly through intake air courses, distances 3000 feet in some instances and up to 4500 feet in one case. And extended experimental tests on a Wyoming coal containing less combustible matter and much more ash and moisture than the Kemmerer coal, or in fact than almost any Southern Wyoming coal, prove definitely that all these coals will, when dry and sufficiently finely divided, ignite and explode unless mixed with well over 50% of inert (non-combustible) matter. For a description of the above mentioned tests see U. S. Bureau of Mines Bulletin No. 167, particularly Pages 255 to 260.

The basis for the impression of non-participation of coal dust in the Kemmerer explosion is the fact that there were very few coke deposits seen after the disaster. It is true that coke was found in only a few places and then in comparatively small quantities, yet there certainly was coke found on the 30th Level and also on the 27th. The lack of heavy coked deposits is probably due to the fact that while dust certainly entered into the explosion, the region on the 30th Level at mouth of Rooms 7 and 8 was damp to wet, thus tending to stop the explosion almost at the start and had this part of the mine been as dry and dusty as for instance the 27th Level, the disaster would undoubtedly have been given a much more violent start, have done

much more damage and have been much more widespread. While the floor and to a less extent the timbers on the 30th Level in the vicinity of the mouth of Rooms 7 and 8 were damp to wet, the ribs were dry and probably held just enough fine dry dust to propagate the explosion both inbye and outbye, otherwise the explosion would have died upon leaving Rooms 7 and 9. On the other hand there was not sufficient dust available to give excessive force or velocity to the explosion at the start and this in turn helped materially in the drier parts of the mine because when the flame reached these dry places (especially in the slope and in the 27th Level) the velocity was so slow that comparatively little dust was stirred up and the explosion was really only a slow inflammation which, on the one hand accounts for the remarkably little damage done to the mine, and on the other hand accounts for the lack of coke deposited, as the coal dust available was almost entirely consumed in the formation of CO and CO₂ gases, rather than deposited as coke.

Tables 3, 4 and 5 give data as to ten coal and dust samples taken four days after the explosion; two samples of fresh face coal being taken from No. 32 Room neck on the 29th Entry, see Laboratory Numbers 93822 and 93823; one sample of road dust was taken on the main slope about sixty feet from the mouth, Laboratory No. 93824; two road dust samples were taken in the neck of Room 7 off the 30th Entry, Laboratory Numbers 93826 and 93829; three road dust samples were taken in the 27th Entry opposite Rooms 8, 10 and 13, with Laboratory Numbers 93827, 93828 and 93830 respectively; one sample No. 93825, was taken on the 27th Entry at Room 49; and a sample of dust settled on timbers on the main slope about 100 feet from mouth, see Laboratory No. 93831.

Table No. 3 gives data as to the 7 road dust samples; it will be

TABLE NO. 3

TABULATION OF ANALYSES OF ROAD DUST SAMPLES, FRONTIER NO. 1 MINE, KEMMERER, WYOMING.

SAMPLES TAKEN AUGUST 18, 1921.

By D. Harrington & H. E. Munn.

Num- ber	Can: No.	Lab. Number	Gross Wt. of sample: Pounds	Amount of Sample Thru 20 Mesh (Analyzed) %	Sizing of Thru 20 Mesh Material				Proximate Analyses "As Received" Basis				Ratio Volatile to Volatile plus Fixed Carbon		
					Wt. Grams	Thru 20 Mesh	Thru 48 Mesh	Thru 100 Mesh	Thru 200 Mesh	Mois- ture	Vol.: Mat.	Fixed Carbon		Ash	Total
1	Z-10	93824	25	54.00	558.00	100.00	49.50	26.50	10.30	3.90	36.10	43.30	16.70	100.00	.455
2	Z-56	93825	30	45.10	418.00	100.00	36.00	13.80	11.40	10.00	34.40	40.40	15.20	100.00	.460
3	Z-73	93826	25	56.20	373.00	100.00	46.50	25.60	12.30	7.10	28.30	35.20	29.40	100.00	.446
5	Z-15	93827	20	47.60	622.00	100.00	50.60	30.00	16.30	7.30	28.90	36.00	27.80	100.00	.446
6	Z-98	93828	22	39.00	432.00	100.00	44.90	20.20	6.70	10.00	29.00	36.30	24.70	100.00	.444
4	Z-86	93829	25	42.30	437.00	100.00	55.20	31.80	26.10	7.40	27.60	34.00	31.00	100.00	.448
7	Z-96	93830	40	51.00	616.00	100.00	54.70	30.50	14.40	7.90	30.80	37.00	24.30	100.00	.454
Average			26.7	47.9	494.00	100.00	48.2	25.5	13.6	7.7	30.4	37.6	24.3	100.00	.450

NOTE: Above samples were taken of a 6-inch width trench to a depth of not over one inch in road dust, going from rib to rib, rejecting all material which would not go through the scoop sieve. The gross sample after being weighed, was coned and quartered to 4 pounds and placed in a sampling can and sealed.

noted that at each place sampled there was obtained over 20 pounds and as high as 40 pounds of material through mesh of the scoop sieve from a trench six inches wide and one inch deep, the trench extending from upper to lower rib of the entry. This means that there was at least 40 to 80 pounds of this size dust per lineal foot of entry at the places sampled and of this an average of about 48% went through 20 mesh, hence, if sufficient combustible were present, could participate in the propagation of an explosion. Of the material that went through 20 mesh an average of 25.5% went through 100 mesh hence was definitely explosive if sufficient combustible were present, and 13.6% went through 200 mesh and was dangerously explosive. The average analysis of the 7 road dust samples was moisture 7.7% or less than 2% greater than the moisture content of the coal in place (see Laboratory Numbers 93822 and 93823, Table No. 4); average ash content of the 7 road dust samples was 24.3% against ash in coal in place about 4%. The average ratio of volatile to volatile plus fixed carbon for the 7 road dust samples was .450 which according to data observed in the investigations at the experimental mine at Pittsburgh, places every one of these samples of road dust, where size was less than 20 mesh, as definitely explosive (See Pages 25 and 342 to 345 of the U. S. Bureau of Mines Bulletin No. 167).

Particular attention is called to samples 93824 and 93831 in Table No. 4; No. 93824 was a road dust sample taken in the main slope about 60 feet from the mouth in a long dry dust zone and analysis shows low moisture content, 3.90% which is materially less than moisture content of the fresh coal at the face 5.80% (See Laboratory No. 93822); the total ash was 16.7, hence total incombustible was 20.60% and the ratio of volatile to volatile plus fixed carbon .455, hence decidedly explosive as to chemical composition.

TABLE NO. 4.

ROAD AND TIMBER DUST COLLECTED AT FRONTIER NO. 1 MINE, KEENEWER, WYOMING

Lab. No.	Kind of Dust	Proximate Analyses "As Received" Basis				Incombustible: Moisture Plus Ash	Sizing Thru 20 Mesh	Sizing Thru 20 Mesh					Sizing - 200 Mesh	Total	
		Mois- ture	Vol.: Mat.	Fixed: Carbon	Fixed: Ash			Material	Material	Material	Material	Material			Material
		Mois- ture	Vol.: Mat.	Fixed: Carbon	Fixed: Ash	Plus Ash	V+P.E. %	Wt. Grams	-48	-100	-200	+250	+325	-325	%
93824	Road	3.90	36.10	43.30	16.70	20.60	.455	54.00	558.00	49.50	26.50	10.30	0.20	9.70	90.10
93825	Road	10.00	34.40	40.40	15.20	25.20	.460	45.10	418.00	36.00	13.80	11.40	43.20	5.70	51.10
93826	Road	7.10	28.30	35.20	29.40	36.50	.446	56.20	373.00	46.50	25.60	12.30	0.40	24.40	75.20
93829	Road	7.40	27.60	34.00	31.00	38.40	.448	42.30	437.00	55.20	31.80	26.10	43.00	8.50	48.50
93827	Road	7.30	28.90	36.00	27.80	35.10	.446	47.60	622.00	50.60	30.00	16.50	5.90	15.20	78.90
93828	Road	10.00	29.00	36.30	24.70	34.70	.444	39.00	432.00	44.90	20.20	6.70	0.50	19.30	80.20
93830	Road	7.90	30.80	37.00	24.30	32.20	.454	51.00	616.00	54.70	30.50	14.40	0.40	27.50	72.10
93831	Timber	5.30	32.50	31.20	31.00	36.30	.510	84.60	441.00	89.80	80.80	67.40	1.60	16.80	81.60
Totals:		58.90	257.60	293.40	200.10	259.00	3.663	419.80	3897.00	427.20	259.20	165.10	95.20	127.10	577.70
Averages:		7.36	30.95	36.67	25.01	32.37	.458	52.47	487.12	53.40	32.40	20.64	11.90	15.89	72.21
93822	Face	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	Sample	5.80	38.20	51.90	4.10	:	.424	:	:	:	:	:	:	:	:
93823	Face	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	Sample	5.90	38.10	52.00	4.00	:	.423	:	:	:	:	:	:	:	:

- 93824 : Taken 60 feet inside of main slope entrance.
- 93825 : " On 27 Entry opposite Room No. 49.
- 93826 : " at neck of No. 7 Room off 30 Entry.
- 93829 : " at neck of No. 7 Room off 30 Entry.
- 93827 : " on 29 Entry inby No. 8 Room.
- 93828 : " on 29 Entry inby No. 10 Room.
- 93830 : " on 29 Entry inby No. 13 Room.
- 93831 : " from 60 lineal feet of timber cap-pieces on Main Slope, 100 feet inby entrance.
- 93822 : " from No. 32 Room neck on 29 Entry.
- 93823 : " at No. 32 Room neck on 29 Entry.

The dust collected in the scoop had 54% through 20 mesh hence could enter an explosion and of the through 20 mesh material 26.5% went through 100 mesh and 10.3% through 200 mesh, and of the through 200 mesh material 90% went through 325 mesh, hence should a trip be wrecked at this point, there would be stirred into the swiftly moving intake air large quantities of very dry, very fine, highly explosive dust, which under certain conditions would be readily ignited by an electric arc or by almost any kind of flame. Sample #93831 consisted of settled dust swept off 60 lineal feet of timber caps located about 100 feet inside of the mouth of the main slope. The analysis of this dust showed 5.3% moisture with 31.0% ash, a total of 36.3% incombustible matter, but the dust was so finely divided that 84.0% of the sample as swept off the timber caps went through 20 mesh and of this through 20 mesh material 80.8% went through 100 mesh and 67.4% through 200 mesh while 81.0% of the material through 200 mesh went through 325 mesh. Bureau of Mines tests at the Pittsburgh Laboratory indicate that although this settled dust on the timber caps had $5.3 + 31.0 = 36.3\%$ of incombustible matter, the dust is so fine that to make it non-explosive would require that the incombustible content be at least 62.5%. There is every reason to believe that the propagation of the explosion in the lower levels of the mine through region of wet to damp floor was due chiefly to small quantities of settled dust on timbers or to small quantities of settled dust on timbers or rib ledges with size and composition similar to the above discussed settled dust sample. Samples 93824 and 93831 were taken at approximately the same place on the main slope and it can be readily seen that the

wrecking of a trip at that (or any similar point) with stirring up of floor or road dust and simultaneous letting down of timbers with the dangerous concentrations of very finely divided dusts settled on them, would fill the air with material practically as explosive as methane. And even if there should be no flame at hand to explode it at the time, this very fine material would be swept along by the intake air to be later deposited along ribs and on timbers at or near working places where flame may be had from electric pumps, or from blasting or from the mine fires, etc.

Samples 93827, 93828 and 93830 taken on the 29th Main entry at Rooms 8, 10 and 13, respectively, give a very definite idea of the dust condition in at least some of the haulage entries before the explosion as the region where the samples were taken was not entered or affected by the explosion. The analyses show that the dust was dry, fairly finely divided, had large amount of combustible matter and was decidedly explosive as indicated by ratio of volatile to volatile plus fixed carbon and by amounts of incombustible necessary to make the dust non-explosive as compared with amount of non-combustible actually present (See Table #5). If there hadn't been a decidedly wet zone near mouth of this entry to quench the flame, there is every reason to believe the explosion would have gone as far in the 29th Level as it did in the 27th where there was no wet zone to stop the flame and where the dust condition was essentially similar to that of the 29th. Sample #93825 was taken on the 27th Entry opposite No. 49 Room at about the point where the flame and small amount of force died away on the 27th Level, there being decided evidences of flame on this entry at mouth of Room 47, but none at or beyond (inbye) Room 49. This sample shows an abundance of dust of suf-

efficient fineness and combustibility to enter into the explosion and probably the only reason the explosion died here was the fact that practically throughout its entire path of over 3000 feet through the 27th Level up to Room 49, there was very little violence, hence the floor dust was not stirred into the air and the only dust available was the comparatively small amount along ribs and timber caps and on the surface of the road material.

Table No. 5 gives summarized data as to the explosibility of the 7 road dust samples and the one sample of settled dust on timbers using sizes and composition as sampled. Since the higher the ratio, $\frac{\text{volatile}}{\text{volatile plus fixed carbon}}$ the more explosive the dust, it will be noted that the settled dust on timbers was by far the most explosive. The total amount of inert material required to make this sample of settled dust non-explosive as determined by the Pittsburgh Laboratory of the U. S. Bureau of Mines was 62.5% and as sampled the total inert was but 36.30%. The average total amount of inert material required to make the entire 8 samples non-explosive was 51.4% against actual incombustible average of 32.37% as sampled. If instead of considering the sizes as sampled, the comparison was based on all material through 200 mesh, there would be required an average incombustible content of 62.7% to make these dusts non-explosive.

Sprinkling and Humidity:

While the mine pumps a large quantity of water and there were found numerous places on the main slope and in some of the levels which were damp or even wet, in general the mine cannot be rated even damp. The coal as mined at room faces is dry and only infrequently is moisture of any kind found in the rooms all of which have a pitch of 15 to 20 degrees. In some places the floor of the 28th and 30th Levels is wet and it is said that before the explosion

TABLE NO. 5

SHOWING EXPLOSIBILITY OF DUST
and
AMOUNT INERT MATTER TO RENDER NON-EXPLOSIVE

Lab.No.:	Can No.:	<u>v</u>	FC	Total Inert Material (Ash & Moisture) As sampled.	Total Inert Material In Non-Explosive Mixture
93824	Z-10	.455		20.60	47.4%
93825	Z-56	.460		25.20	45.9%
93826	Z-73	.446		36.50	51.1%
93829	Z-86	.448		38.40	53.4%
93827	Z-115	.446		35.10	51.4%
93828	Z-98	.444		34.70	48.7%
93830	Z-96	.510		32.20	50.5%
93831	Z-83	.510		36.30	62.5%
Average:		.458		32.37	51.4%

NOTE: The data contained in this tabulation is based on sizing tests and chemical analyses of the material as sampled underground.

most of the timbers were damp to wet in those levels though at time of the mine inspection after the explosion the ribs and timbers as well as the floor in many places in the 28 and 30 entries were dry. The 27th Level would be rated somewhat dry throughout, though some roof moisture was seen in one of the rooms off the 27th level, one of the few places where any moisture was noticed in rooms at face or on roof, ribs or floor. The 29th Entry was dry also, except that near the mouth of the 29th main haulage entry starting about 100 feet from the main slope there was a zone of water drippers extending for a distance of 200 to 250 feet into the 29th Level. There was found ample evidence that the flame went through the parting on the 29th level at the slope and penetrated at least 100 feet into the zone of water drippers, but it did not go through the wet zone as no flame or violence was found inbye the above mentioned wet zone though the amount of water dripping from roof would not even dampen the clothing when walking slowly through its extent of 300 to 400 feet and the amount of water on floor was sufficient to keep the floor dirt decidedly damp without causing any considerable amount of mud. The presence of this zone of water drippers near mouth of 29th Entry undoubtedly prevented extension of the explosion into the interior of the 29th Level and thereby undoubtedly prevented heavy additional loss of life since at least 21 men came out of this level alive several hours after the explosion.

Inspection after the explosion of parts of the mine not entered or affected by the explosion indicates that practically no systematic effort was made towards elimination of the dust hazard. While large quantities of water were pumped from the mine and there were connections from pump column at intervals along the main slopes with one inch pipes into levels, there

were no water lines into rooms and no person or persons were detailed definitely to sprinkling work. Moreover there was no provision for sprinkling of coal on cars and no placing of permanent sprays or humidifiers. The system of mining and of haulage were of a nature tending towards formation of maximum quantities of dust and of their spread through the workings; among the harmful practices being blasting off solid, use of mine car with end door, placing of rooms up the pitch with necessity of handling all room coal by McGinty, etc.

Dust sampling was confined to entries where it was felt that safest conditions would be found as the entries in this mine being along the strike are more likely to be wet or damp than are the rooms which are on the pitch, moreover the dust in rooms is much more likely to be free of dirt than would be the dust on the haulage entries, hence room dust would be much more dangerous than dust on entries. The dust samples taken on entries showed very small moisture content and large percentage of combustible hence both rooms and entries contain dangerous conditions as to dust and the entire mine should have systematic humidification.

Electricity:

Experience in recent years has proven that electricity is one of the greatest aids, as well as one of the greatest hazards in modern coal production. In this mine electric current is used for pumping and lighting, and in general the necessary lines are well places and the upkeep carried on in a fairly workmanlike manner. In the upper part of the mine, the three phase lines consist of three wire cables carried down the return airway, branching off and feeding the pump units. However, in one case, the feeder cable for the

No. 26 pump station crosses over the main slope to the pumping station. This condition is decidedly dangerous, as a runaway trip or wreck on the slope at this point could, and probably would, dislodge this cable, with consequent short circuiting; flame sufficient to ignite the fine explosive dust thrown into suspension. On the lower end of the main slope the feeder for the lower pump runs along the right rib and very close to the trip. This affords a condition equally or possibly more hazardous than that existing at the 26 pump station. Immediate steps should be taken to lay the feeder at the 26 pump station under the track in suitable conduit or enter it into a groove in the roof; and the cable from the bottom pump should not be located on the haulage roads, and especially not on the main slope. If electricity should ever be used for haulage or other purposes in this mine only permissible equipment should be allowed and where at all feasible electrical equipment should be in the intake air.

Haulage Dangers, Fire hazards, Etc.

The handling of men on the main slope over a mile on pitch over 15 degrees in the ordinary mine cars is dangerous, and it is suggested that a safety man trip be provided somewhat like the one in use at Gebo, Wyoming or at Reliance, Wyoming; the blocking of mine cars near room face by a prop with one end against lower part of car and other end of prop on floor is dangerous and a better method would be to place a tie or prop across the track near lower end of car with another prop extending under the car towards face of room parallel with track and lower end of this prop on the transverse tie or prop before mentioned. The stable constitutes a definite fire hazard and at both ends there should be placed tight doors such that in case of fire in the stable the closing of the two doors would isolate the stable from the mine. Similarly

the pump houses should be provided with doors and pump houses, stables or other underground gathering places or places housing machinery should be fire proofed as far as feasible and have readily available fire extinguishers and water lines, and hose that in case of emergency water may be available without loss of time.

Shooting off the solid is a decided fire menace in a gaseous mine, especially when black powder is used; using permissible explosive with electric blasting would tend to eliminate this trouble but a better method would be to change the system of mining to that of panels with rooms across the pitch which would allow of undercutting of coal and use of small charges of permissible explosive shot by electricity. This mine is fortunate not to have had previous explosions due to its numerous fires and also due to use of fuse and black powder in gaseous places.

General Safety Conditions:

The outstanding feature in connection with this explosion is the carelessness displayed in methods used in connection with methan and dust in a coal mine. While closed lights were used exclusively and much attention was paid to use of brattice cloth, overcasts, etc., to distribute air, yet the quantity in each split near working portion of the mine was entirely inadequate. Explosive gas issues almost constantly and is said to be especially likely to issue in jets from floor at blasting time, yet black powder with its enormous flame was used, moreover, it was shot "on the solid" hence demanding heavy charges which not only tore down the tender roof and smashed the coal into fines but also ignited wither the dust or gas and it is said frequently brought about such ignitions. While these conditions and methods are

decidedly dangerous, the fact that entry men could blast at any time and room men were allowed to blast at noon with the entire shift in the mine, made the conditions particularly dangerous. And while the mine was felt to be sufficiently gaseous to require use of closed lights exclusively, yet all men were allowed to carry into the mine and use ordinary matches for smoking and for lighting of shots or of flame safety lamps.

Those using the flame safety lamp either did not realize the dangers of methane and the limitations of the flame safety lamp or deliberately ignored them thus risking not only their own lives but those of all the mine workers, and at the same time risking the destruction of the mine. While modern flame safety lamps were used, the magnetic locking device was made inoperative, the friction ignitors were removed and plugged or at any rate were not used and if flame on a safety lamp should be extinguished, the lamp was taken apart and flame reestablished by lighting an ordinary match, this being the general, probably the universal practice, and the justification for this practice by users of flame safety lamps is the fact that matches were used at any time throughout the mine for smoking and for lighting shots, hence why not for relighting safety lamps?

The fact that the mine had a large quantity of water to handle and that some parts of the mine were decidedly wet, together with the knowledge that Wyoming mines, especially those around Kemmerer, had been singularly free of dust explosions, seems to have given the local management the definite impression that the dust of this coal is practically if not wholly non-explosive. Hence little if any attention was paid to elimination of the dust hazard. This attitude as to the practical harmlessness of coal dust in Wyoming mines is almost general among coal mining men in Wyoming; so much so that after the Kemmerer explosion, Wyoming operators in more or less general

touch with the conditions in the mine after the explosion, claimed that dust was not a factor, yet these people fail to explain how flame could be carried nearly a mile through intake air courses unless dust did participate.

The explosion had remarkably little strength, resulting in very little damage to the mine, yet there was a large amount of flame as Room 7 was scorched from roof to floor from face of room to its mouth, splinters on timbers were charred or burnt along the 30th Level even where the timbers were damp to wet, there was considerable charring of timber splinters at various points in the main slope up as far as the 15th Level and in the 28th Entry approximately as far as Room 20. In the 27th Level while apparently there wasn't enough force to tear out brattice curtains, yet there was enough flame to start nearly all of them burning also to start some timbers burning, the flame extending as far as the curtain across the entry inside Room 47; however, while as above indicated, there were numerous instances where dry brattice and a few places where timber was ignited yet the fires were all extinguished before rescuers arrived, probably due to the fact that the slow explosion or inflammation had consumed practically all of the oxygen available.

Only in the 30th Level did the explosion enter into rooms and in most of the other working levels the rooms were comparatively free of not only violence but also of flame and of noxious gases and had all men remained at faces (especially if they had bratticed off these places) it is probable that the death list would not have reached 30. Even had those who forced their way through the fumes and found death, been equipped with the so-called self-rescuers, it is very probable that they would have been killed as the extinguishment of the fires above mentioned shows definitely that oxygen content of the air on the haulage entries (hence the probable path of those seeking escape) was too low to sustain life. Moreover if the men had been equipped

with self rescuers or any kind of gas mask which is not self contained or does not supply oxygen, they would probably have attempted to rush through the highly heated smoky atmosphere and even had there been sufficient oxygen to sustain life and even should the masks absorb the poisonous fumes, the highly heated air would either have killed them due to external contact or have so affected the lungs and bronchial passages that death would ensue. In this explosion, as with several others with which we are acquainted, it seems apparent that the best procedure for live men trapped after an explosion is to barricade and await restoration of ventilation.

There appear to be at least three men who are deserving of credit in connection with the barricading in the 29th Entry. Mike Pavlisin, Clifford Phillips and John Worhol, though apparently Pavlisin is the one to whose good judgment the rescued men owe their safety.

Of the 99 men killed, about half were married, nationality of victims being Italians, Japanese, Americans, Finlanders, Mexicans, Slavs, the list being given in about the order of number of each nationality killed.

It is noteworthy that the mouth of Room 7 off the 30th Level where the explosion had its origin is on land belonging to the U. S. Government and operated by the Kemmerer Coal Company under lease arrangement; however, the face of Room 7 where the gas was actually ignited, is on land belonging to the Kemmerer Coal Company. The 30th Entries as well as future workings below them are on Government land, hence must be operated under Government Regulations For Operation of Mines on Leased Lands.

RECOMMENDATIONS:

The following is a detailed list of the recommendations and suggestions which occur to us, with the idea of making an effort to solve some of

the problems which should be met in this property if it is to continue in operation. Probably some of these recommendations are already in effect, and many of them may seem to the management as entailing excessive expenditures, but we believe that none of them should be discarded without carefully weighing them against the expense and misery entailed in an explosion.

1. A new ventilating fan of an approved type should be installed. This new unit should have a capacity sufficiently large to take care of the present active workings as well as providing means of increasing the volume under conditions of future development; capacity should be at least 100,000 cubic feet per minute at and below the 27th Level, giving 20,000 to 25,000 cubic feet per minute to each main split. It should be equipped with the reversible feature as well as with explosion doors of an approved type, and should be located on a right angle offset from the main return air course. In addition to the above it would be advisable to have an auxiliary engine probably operated by steam, so arranged that power could be quickly and easily applied to the fan in case of interruption of the normal electric power supply.

2. Due to the extreme length of the air-courses, it is essential that every thing feasible be done to increase the area of the return air-courses. Inspection of these returns, especially the back entries showed that areas were much reduced by falls of rock. These main air courses should be cleaned, straightened and freed of unnecessary obstructions.

3. The mine shows a low water gage, about $2\frac{1}{2}$ inches, which is lower than it should be for the area and length of the air courses, indicating that considerable leakage occurs in the upper workings. Observations would seem to indicate that the greatest part of the trouble takes place above the 14 Entry. The stoppings between main intake and main return should be tightened and it is suggested that gunniting would be a quick, cheap and efficient method of

doing this. Gunnite could also be used to advantage on the stoppings in the cross cuts between levels. We recommend also that a suitable water gage be installed at the fan, and that daily records of the water-gage readings be made in a suitable book kept especially for this purpose.

4. As entries are worked out and abandoned, they should be sealed.

5. The present fan, with it's oil soaked timber housing constitutes a fire hazard. It would be desirable to have this fan held in readiness for stand-by operation after the new unit is in operation, but in order to eliminate the fire danger the wood housing should be fire-proofed, preferably by the use of gunnite both inside and out. Also the fan approach should be tightened by gunniting or otherwise, and it is probable that occasional cleaning of grease and other dirt from fan blades would materially increase the efficiency.

6. Great care should be exercised in the selection of the underground officials, particularly fire-bosses and shot-firers. They should be careful, conscientious men, and there should be a sufficient number of them to allow each man to make a careful examination of the places in his territory in the case of fire-bosses, and in the case of shot-firers, that all shot holes are carefully inspected before and after loading.

7. No flame safety lamps, except those of the magnetic lock type, should be allowed in the mine, and they should be used only by foremen, fire-bosses and shot-firers who understand the lamps and their dangers and limitations. It is suggested that while the shift is in the mine foremen, fire-bosses and shot firers use the Burrel Methane Indicator instead of flame safety lamp, to test for gas.

8. The practice of moving gas while men are in the mine should be discontinued.

9. Regulations as to the use of explosives and general shot-firing practices should be posted at conspicuous places on the surface and in the mine, and every one should be compelled to become familiar with these regulations and abide by them.

10. Provision should be made to check all shot-firing, ventilation and other safety methods and practices at frequent intervals in order to prevent carelessness of underground employees. The employment of a competent safety engineer full time for service in all mines of this company and reporting to both lower and high officials but responsible only to high officials should accomplish the above.

11. The present system of using black powder with fuse and squibs should be discontinued, and only permissible explosive used in conjunction with some form of electric shot-firing. The amount of permissible explosive used in any one hole should not exceed $1\frac{1}{2}$ pounds, and nothing but clay or other incombustible should be used in tamping holes.

12. The practice of firing shots with men in the mine should be discontinued; this may be considered impracticable, but it has been done successfully in other places using the same system of mining and blasting in coal much thinner and more difficult to shoot than that at Kemmerer.

13. Only electric cap lamps which have a positive lock on the battery and are otherwise maintained in accordance with the schedule prescribed for their permissibility, should be allowed. The practice of locking a certain percentage of the lamps with cotter pins and nails is dangerous and should be discontinued.

14. It is recommended that smoking be prohibited underground and that carrying of matches underground for any purpose be prohibited. It is

advisable to institute a systematic method of searching all underground men for matches and smoking materials. This searching should be done frequently, and the men doing the searching should be changed at irregular intervals. It is also a good plan to have men searched underground occasionally.

15. The present sprinkling system should be enlarged and extended so that sprinkling can be efficiently carried on on all entries and haulage roads and also at room faces. The working places, both rooms and entries, should be thoroughly wet down before firing shots, and loaded cars should be well wet down before the car leaves the face.

16. In a mine of this size, there should be at least two men employed exclusively on sprinkling work, and they should not be employed on other work unless ordered by the superintendent. Sprinklers should be required to make daily reports as to the amount of work accomplished, as well as to difficulties with equipment, such as pipe breakages, leaks, poor pressure, interference by bosses or workers, etc.

17. In the sprinkling operations, the roof as well as the ribs and gobs should be thoroughly wet down. Sections of hose should be provided for workers at face of each room and the workers required to wet down region of face several times per day if the region is not actually damp.

18. Rules and regulations covering the sprinkling operations in the mine should be drawn up, and every precaution be taken to see that they are followed to the letter.

19. In those sections of the mine where sprinkling is not feasible due to low winter temperatures or to tender roof, it is recommended that rock dusting be used. This rock dusting to be effective must be systematically done, and must include the dusting of floors, ribs, roof and timbers. For rock dusting practice, consult U.S. Bureau of Mines publications, particularly Bulletin 167.

20. The rock dust to be used should be subject to chemical and microscopic examination before applying it, in order to determine it's suitability both as to effect on health and as to its safety and efficiency. The Bureau of Mines station at Pittsburgh is equipped to do the work.

21. Rock dust barriers constructed in accordance with the specifications of the U. S. Bureau of Mines should be placed across the main and back entries of all working entries near the slope, as well as across the entrances to any portion of the mine considered to be particularly dangerous as to gas and dust. Unless these barriers are correctly placed and constructed, they will be useless. For correct construction see U. S. Bureau of Mines Bulletins 20, 56 and 167 and Technical Paper #84.

22. The mine apparently has large coal reserves, and it is suggested in the interest of safety and efficiency that operations below the 29th and 30th levels should be carried out along the lines of the room and pillar panel system, such as is in successful use at the Gebo Mine in Wyoming. The use of the panel system would make it possible to use electric mining machine for undercutting the coal, thereby eliminating the present bad practice of "shooting off the solid." The roof is tender and with the present methods of shooting with heavy charges of black powder, an excessive amount of roof material is brought down.

23. The stable is a fire hazard, and should be equipped at both entrances with fire-proof doors, also with fire extinguishers and with hose and ready connection to water line.

24. A better method of holding cars at face of rooms consists of placing a prop or tie across the track just in front of the car, and then running in a prop or timber under the car between the bumper and the cross

timber, and in line with the track. Cars cannot get away with this method and it is suggested that the above method be substituted for present system.

25. A man-trip provided with safety equipment should be used in place of the present coal trip, for lowering men into the mine. There are two "Safety Man-trips" in successful operation in Wyoming, one at Reliance and one at Gebo; and it is recommended that a trip similar to these be used.

26. The pump rooms are not sufficiently protected as to fire, and steps should be taken to provide all pump rooms with suitable fire-proof doors, as well as fire extinguishers and hose attached to water column for quick use.

27. On account of the prevalent idea that the dust of this mine is practically, if not wholly, non-explosive, it is suggested that a sample of one to two tons of coal from Frontier No. 1 Mine be sent to Pittsburgh Testing Laboratory and subjected to the usual tests as to explosibility, the officials of the company to be present during tests and the company to supply the coal and pay the freight cost to Bruceton, Pennsylvania, where testing would be done.

28. In order to keep up to date in safety, it is suggested that the Kemmerer Coal Company have all of its properties examined at least once a year by a competent outside safety man or it may be advisable to establish a system of exchange of annual safety examinations with other coal companies, such as the Colorado Fuel & Iron Company, Utah Fuel Company, United States Fuel Company and Union Pacific Coal Company.

ACKNOWLEDGMENTS

The writers wish to express their appreciation of the help and co-operation offered by General Manager Quealey and other officials of the Company, in allowing Bureau of Mines representatives to enter the mine to aid in

the rescue and recovery work and to obtain data as to causes and effects of the explosion. They also wish to thank the Pittsburgh Station for their promptness in supplying analyses of mine air and coal and dust samples, as well as for their work on furnishing sketches and maps, and also for furnishing interpretations of explosibility of dusts.

APPENDIX NO. 1

CORONER'S INQUEST

of

FRONTIER NO. 1 MINE EXPLOSION, FRONTIER, WYO.

on

August 14, 1923.

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APPENDIX NO. 1

Coroner's Inquest:

On August 17th the Coroner's Inquest rendered the following verdict in regard to the mine disaster:

"We, the undersigned jury, empaneled to determine the cause of the explosion in No. 1 Mine, Kemmerer Coal Co., come to the conclusion that the explosion was caused by gas being lit by the Fire Boss while uncoupling his lamp and as a result of the explosion all victims are dead."

(Signed) George Brown,
Joe Bird,
Wm. McAllister.

Coroner's Jury."

The following extracts from testimony taken during the course of the Inquest are of interest in their bearing on the human element:

John Oakley, Mine Foreman: "Fire Boss Sager reported all clear in 29 and 39 entries. Shot Firer Roberts working on 27, 28 and 29 entries found gas in 27 entry in 45 room. I ordered Roberts to shoot in 30 entry and Sager to shoot in 28 and Safety Inspector Wainwright to remove gas from room 45 off 27 entry. 102 miners and 34 company men were checked into the mine the morning of the explosion. When I was ready to go down, I saw smoke coming out of the fan. I sent 3 men down the slope to examine the stoppings off the slope. On the slope, between 14 and 15 entry, I found the pumper dead. The trip was at 17 entry and wrecked and sent three men to pull pin and then brought empty rope to surface. We built temporary stoppings along the slope and at 11:20 A.M. ventilation was restored to 29 entry. The slope was cleared about 2:00 P.M. Found one body on slope between 28 and 29 entries, and many at 27 entry. Cleared the bodies off the slope and placed them to one side and then went into the entries. 21 men were alive in 29 entry. The explosion occurred about 8:20 A.M. caused by Fire Boss lighting his safety lamp in a body of gas in room 7 off 30 entry. The bottom of the safety lamp was unscrewed from the top and was found about 8 feet from the face. Tom Roberts, gas man, was a certified man. John Sager, Jr. reported No. 7 room on 30 entry clear of gas and was working in 28 entry detailed by myself to examine shots until noon. Tom Roberts was regularly shot firer on 30 entry and was temporary fire boss in the 14th. Gas men upon finding a body of gas are supposed to block off the entrance, report in book, and to Foreman and then remove the gas. 50 feet of gas was reported in No. 45 room off 27th entry. Safety Inspector Wainwright and the Shot Inspector cleared room 45 off 27 entry. Roberts, Shot Firer, went up to the face of room 7 before he ate his breakfast. The caprock in the mine falls at times and disarranges brattice after fire boss leaves and before men come in. Shots fired in rooms at noon and at the end of the shift, and at any time in the entries. Supposed to inspect all shots before tamping.

The explosion in 27 entry went as far as room 47. Men came out of the face of 27 entry alive. Very little violence or flame found in 29 entry. The explosion split at the bottom of room 7 and 8 in 30th entry. The fire boss and miner in No. 7 room were badly burned. The night pumpman leaves at 8:00 A.M. and was out of the mine. The day pumpman was going up the slope to the upper pumps and was burned and killed near 27 entry. There is a fire on the south side of the mine which is sealed off and a good current of air in each entry. There were 21 miners in 30 entry. The air is measured once a week. There was 1,000 cubic feet of gas in room 17 off 30th entry on August 13, due to falling of rock on the brattice. No shots had been fired in No. 7 room the morning of the explosion. Wolfe flame safety lamps and Wico electric cap lamps are used. Flame safety lamps used only by gas examiners. Tom Roberts was the only shot firer who had a certificate. John Sager, Jr. was Fire Boss 7 or 8 months."

Clifford Phillips, driver in 29 entry: "I have the inside drive on 29 entry. They were getting ready to fire shots at the face of the back entry when I made the first trip in. Was waiting at 21 slant when I heard concussion and soon the miners came out of the rooms. The back entry shots had gone off several minutes before the concussion was felt. It was about 8:20 or 8:25 when the concussion came. The other drivers had not yet come in as far as 21 room. We bulkheaded the inside part of the entry completing the bulkhead in the back entry about 2:00 P.M. We put up 3 canvas brattices and one rock stopping."

Joe Nagi, Miner in 29 main entry: "Face of 29 main entry is about 33rd room. I felt ringing in my ears, back and forth, then went out towards the slope, ran into gas, then ran back. Went out as far as No. 1 room and was pretty near knocked down, and then went back and worked on stopping. Men came down from 27 (probably thru No. 4 room) and said 21 men were in 27 and all of these came to 29. Then all were brought to the surface about 3:00 P.M. The coal is $8\frac{1}{2}$ to 9 feet thick."

Mike Pavlisin, shot inspector on 29: "Met smoke several places and went to the slope twice but turned back by smoke. Some men in hurry wouldn't wait but never came back. Smoke about No. 2 room at first and then to No. 3 room. Went up to 27 entry through No. 4 room. Went back to 29 with 28 men. Do not examine all shots in narrow work. Never shoot shots when gas is around. Always have good air."

M. Fukamutsu, Jap Miner from 28 entry: "Was working in 26 room, felt concussion and "wind." Then go to crosscut, and then down to entry, but smoky. Go back, sit down long time. Go down again to entry. Much smoke. Go out to parting 11 o'clock and smoke too hot and see many dead men. So go back and wait long time for men. Men came about 5 o'clock and me and partner go out about 5:30."

Tom Russell, Mine Supt., Diamondville, Wyo. "I heard of the explosion about 9:15 A.M. Got some men and apparatus and went to No. 1 Mine, Frontier. The fan was O. K. Went down and found the trip off the track and small cave in on slope about 17th level. Found man in 25 entry dead and some stoppings out below 25. About 27 entry I met a man alive but partly dazed and soon found a Jap alive and then a man making a noise. The air was following nicely to 27 entry. Found many bodies, some burned, but mostly killed by gas. At 29 the overcast was O.K. and the overcast at 27 was alright. Went into 13 room. 30 entry too strong to go into. Soon heard a noise in 29. The pump stopped. Then went into 27 and 29 and others went into 28. Then Cumberland apparatus crew came and went into 30, but found much gas and compelled to ventilate. Found slant door broken at 11th room and repaired it. Found a few stoppings out in the 30th and more violence than on other levels. Men in 30 (4 were picked up between end of parting and 12 room) were killed as they stood, burned. South side of timber dirty but north side clean. No. 30 entry was wet. Stayed at room 12 until 12:15 to 12:30 after midnight and men all in, then came out reaching the top about 1:15. Went as far as room 15 on 30 entry but encountered no fire damp."

Peter Bohm, No. 1 Mine Cumberland: "I was told of the explosion at 10:50 A.M. Supt. Brown ordered me to get apparatus in shape and landed at Frontier at 12:30 and waited for the Bureau of Mines. Two teams were then organized going in about 2:00 P.M. to 30 entry. Empty cars at face of 30 main entry were not touched. Little evidence of violence at fan. Miners had been drilling hole at face of main entry. Found 2 bodies in back entry and pulled them out. Brattices were blown out in room 17 and 18 and No. 11 room was in bad condition. Jap was burned at face of No. 7, found by Sullivan and body brought to entry. I am shotfirer and certified man. Aided Sullivan and Birchard in finding safety lamp open and match burned near the pot or lower part of the lamp."

Roberts, Fire Boss. (Brother of Tom Roberts who was killed in explosion). "Do not use locks on safety lamps, also do not use igniters and re-light lamp with matches. I have certificate as Gas Inspector from England as well as Fire Boss and Mine Foreman certificates in Wyoming."

Peter Patterson, State Mine Inspector, Southern District: "I was at No. 5 Sublet when informed of the explosion. I arrived about 11 A.M. Mr. Quealey told me that trip had probably jumped the track and stirred up dust causing the explosion. Ventilation had been practically restored. A few small falls were on the slope. One rescue crew went into 29 entry and into 27 entry about 2:30 P.M. Mike Pavlisin and partners came out of 27 and 29 and later on the two Japs came out of 28.

I have been Mine Inspector for the southern Wyoming district since April 1st, and I inspected No. 1 Mine once since then. I took no air measurements as my anemometer was out of order. This inspection was made on May 17. Ventilation was fair, entries clean and damp. Air at intake 46,000, return 52,000. 180 men in the mine and number of head of stock 17.

Some air is taken into the mine through 13th entry through No. 3 Mine. There were no complaints from miners. No shots were fired at face of No. 7 Room as the room was full of coal. There was no blown out shot. It is my opinion that the explosion originated in No. 7 room on 30 entry.

Note: At this point Mr. P. J. Qucaley made a statement with the permission of the Coroner's Jury to the effect that gas comes out of feeders or jets in the shale floor. They have frequent fires at shooting time; had one on Thursday night before the explosion. "Send 'Fire Bug'" around every night after firing shots."

Rex Coates, Engineer: "Mr. Oakley asked for "helmets" by 'phone about 8:30 A.M., and they were fixed and sent up. Three of the "helmet" crew had been killed in the explosion, 3 men went in with "helmets" to 20 entry and then back up to 17 and waited for more oxygen. Russell, Bell, Oakley and others were in the mine at that time. Soon the "helmet" men from Cumberland came. Met two men near 27 slope and took them up to 17 entry. Then went back into 27 entry and at 4 room found chalk mark on coal that many men were in 29. Live men taken out at 3:00 P.M.

APPENDIX NO. 2.

NAMES, CLASSIFICATION and CIVIL STATUS of MEN KILLED

at

FRONTIER NO. 1 MINE EXPLOSION, FRONTIER, WYOMING.

on

August 14, 1923.

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APPENDIX NO. 2.

NAMES, CLASSIFICATION and CIVIL STATUS of MEN KILLED

Name	Age	Nationality	Married or Single	Children	Aged	Residence of Dependents
K. Kirino	53	Japanese	Married	--	--	Frontier, Wyo.
Kanada	35	"	"	--	--	Salt Lake City.
M. Hasoda	30	"	Single	--	--	Japan
F. Miura	33	"	"	--	--	"
S. Masaki	33	"	"	--	--	"
A. Oyama	50	"	Married	--	--	"
S. Mikami	35	"	Single	--	--	
K. Kawahara	35	"	"	--	--	
G. Takasugi	41	"	"	--	--	
T. Hagi	27	"	"	--	--	
C. Hagi	51	"	Married	--	--	Japan
I. Kozaki	36	"	"	2	5-4	Frontier, Wyo.
K. Kojima	22	"	Single	--	--	Japan
K. Baba	29	"	Married	--	--	Japan
K. Itow	32	"	"	--	--	Japan
H. Hobara	30	"	Single	--	--	
S. Kawase	31	"	Married	1	1	Frontier, Wyo.
17 - Married 8, Single 9.				3		
Joe Rodriguez	30	Mexican	Married	2	7-9	Mexico
Tom Sanchez	28	"	"	--	--	Weston, Colo.
Robert Trujillo	37	"	"	2	7-4	Green River, Wyo.
Juan Lopez	30	"	"	2	3-1	Kemmerer, Wyo.
Frank T. Navarro	40	"	"	--	--	Wife in Rawlins, Wyo.
5 - Married 5.				6		
Paul Dujinik	40	Married	Slav	--	--	Frontier, Wyo.
Mike Kusnirik	58	Slav	Married	2	15-12	Frontier, Wyo.
2 - Married 2.				2		
Louis Roberts	30	Canadian	Single	--	--	Caledonia, Canada.
1 - Single 1						
John A. Zumbunnen	24	American	Single	--	0-	
Carl Christensen	29	"	"	--	--	
George Womer	55	"	Married	--	--	Kemmerer, Wyo.
Joe Wainwright Sr.	56	"	"	3	15-11-6	Kemmerer, Wyo.
Joe Wainwright Jr.	20	"	Single	--	--	
Mac Roberts	37	"	"	--	--	
Geo. Essman	35	"	Married	--	--	Kemmerer, Wyo.
John H. Martin	59	"	"	--	--	Kemmerer, Wyo.
Thos. R. Harkin	34	"	"	3	6-4-1	Frontier, Wyo.
J. A. Walton	32	"	"	3	4-2-1	Frontier, Wyo.
Thos. Roberts	26	"	"	1	2	Frontier, Wyo.
John Kiddy	39	"	"	5	9-8-7-6-4	Frontier, Wyo.
Frank Eynon	50	"	"	5	17-15-13-8-6	Frontier, Wyo.
Jno. W. Zumbunnen	39	"	"	6	10-9-8-6-5-3	Frontier, Wyo.
14 - Married 10, Single 4.				26 Children		

Marco Fontina	36	Italian	Married	2	13-10	Frontier, Wyo.
John Savant	27	"	Single	--	--	Italy
E. Girardelli	23	"	"	--	--	Rupert, Idaho.
Geo. Berta	29	"	Married	1	6 mos.	Frontier, Wyo.
W.E.Cappelli	28	"	Single	--	--	
John Castagno	42	"	"	--	--	
Joe Andreatta	31	"	Married	1	2 mos.	Frontier, Wyo.
Louis Andreatta	29	"	"	1	2	Frontier, Wyo.
is Toresani	31	"	Single	--	--	
Ottilio Menapace	26	"	"	--	--	
S. Pismonti	50	"	"	--	--	
Frank Martini	24	"	"	--	--	
Cirillo Mendini	31	"	"	--	--	
A. Bebber	42	"	Married	3	11-2-6 mos.	Frontier, Wyo.
E. Bebber	39	"	Single	--	--	
Joe Rollo	29	"	"	--	--	Italy - Mother
Tony Vito	52	"	Married	--	--	Italy
Marion Pernice	33	"	"	1	2	Frontier, Wyo.-Wife.
Valle Valeriono	23	"	Single	--	--	Italy - Mother
Oswaldo Dodorico	22	"	"	--	--	"
Felix Dodorico	26	"	"	--	--	"
D. Fortunato	26	"	Married	1	1	"
Livio Cavecchio	27	"	Single	--	--	"
Louis Tinpano	33	"	"	--	--	"
John Magnino	34	"	Married	2	7-5	Frontier, Wyo.
Mark Magnino	27	"	Single	--	--	
Angelo Alego	45	"	Married	4	12-10-9-6	Frontier, Wyo.
Joseph Alego	41	"	"	3	13-12-8	Frontier, Wyo.
C. Pellegrini	41	"	"	3	12-14-9	Italy
Fred Loddo	30	"	Single	--	--	
Enrico Desanti	41	"	Married	3	10-8-6	Frontier, Wyo.
John Pierone	40	"	"	--	--	Italy
Pretari Palmyra	37	"	Single	--	--	
V. Coli	38	"	"	--	--	
John Coli	32	"	Widower	1	7	Italy
Mike Citerio	28	"	Married	3	7-3-7 days	Frontier, Wyo.
John Georges	36	"	Married	4	9-6-5-20 mos.	Frontier, Wyo.

37 - Married 16, Single 21. 33 Children

Paul Warhol	21	Austrian	Single	--	--	Frontier, Wyo.
Joe Lupcho	17	"	"	--	--	
Masu Palavar	38	"	"	--	--	
ny Brall	60	"	"	--	--	
J. Grutkoski	34	"	Married	5	11-9-7-5-3	Frontier, Wyo.
Nick Smith	55	"	Single	--	--	
Joe Kovach	43	"	Married	6	15-13-12-9-7-4	Frontier, Wyo.
Val Faustino	45	"	"	1	1	Frontier, Wyo.
Joe Motech	56	"	"	5	13-12-10-7-5-	Kemmerer, Wyo.
John Christian	33	"	"	1	13	Kemmerer, Wyo.
George Lupcho	27	"	"	1	1	Frontier, Wyo.
Andrew Lupcho	53	"	Widower	3	14-17-12	Frontier, Wyo.

12 - Married 6, Single 6. 22 Children.

John Sager Sr.	59	Finn	Married	---	---	Frontier, Wyo.
Matti Erikson	45	"	"	---	---	Frontier, Wyo.
Henry Kangas	33	"	Single	---	---	Frontier, Wyo.
Mike Hill	60	"	"	---	---	
John Sager Jr.	24	"	"	---	---	Frontier, Wyo.
Ag. Jarvie Sr.	50	"	Married	3	15-13-10	Frontier, Wyo.
Matt Metsala	37	"	"	1	3	Frontier, Wyo.
Eino Kare	34	"	"	1	3	Frontier, Wyo.
Hjalmar Metsala	24	"	Single	---	---	
Emil Forsman	31	"	Married	1	10	Frontier, Wyo.
Eino Erikson	20	"	Single	---	---	

11 - Married 6, Single 5. 6 Children.